Knee Surg Sports Traumatol Arthrosc (2012) 20:1463–1469
DOI 10.1007/s00167-011-1691-x

KNEE

Articular cartilage of the posterior condyle can affect rotational alignment in total knee arthroplasty

Yasutaka Tashiro · Munenori Uemura · Shuichi Matsuda · Ken Okazaki · Shinya Kawahara · Makoto Hashizume · Yukihide Iwamoto

Received: 7 May 2011 / Accepted: 20 September 2011 / Published online: 7 October 2011

Abstract

Purpose Rotational alignment is important for patellar tracking, ligament balance, and tibiofemoral congruity after total knee arthroplasty (TKA). The posterior condylar axis is often referred to as a rotational alignment landmark. However, articular cartilage wear localized only in the medial condyle might affect the accuracy of rotation, because surgical planning based on CT does not consider the cartilage thickness. The purpose of this study was to clarify whether the cartilage thickness of the posterior condyle affects rotational alignment after TKA.

Methods A total of 40 osteoarthritis patients waiting for TKA were recruited. MRI of axial sections was performed preoperatively. Scans were controlled to make the cross section perpendicular to the mechanical axis of the femur on the coronal plane and to the tangent line of the distal femur on the sagittal plane, so that the surgical section of the actual femur could be simulated. The condylar twist angle (CTA) was measured with and without articular cartilage. The cartilage thickness on the medial and lateral posterior condyles was surveyed in both MRI images and surgical specimens.

Results The CTA without cartilage (6.8 ± 2.0°) was significantly larger than the CTA with cartilage (5.2 ± 2.0°) ($P < 0.01$), and 12 knees (30%) demonstrated differences of more than 2 degrees. The cartilage depicted in MRI showed almost the same thickness as the actual specimens and was significantly thicker on the lateral condyles.

Conclusions Surgical planning for TKA not considering articular cartilage might lead to the externally rotated malposition of the femoral implant.

Level of evidence II.

Keywords Rotational alignment · Articular cartilage · Total knee · Posterior condyle · MRI

Introduction

The rotational alignment in total knee arthroplasty (TKA) affects patellar tracking, knee alignment, and varus and valgus stability in flexion. Rotational malalignment of the femoral components can cause patellofemoral complications such as patellar subluxation and late patellar prosthesis failure [1, 2, 5, 21]. Ligament balance abnormalities can lead to knee instability and lift-off in weight-bearing activities [16, 29]. In addition, tibiofemoral incongruity caused by rotational mismatch can accelerate tibial polyethylene insert wear [10, 22]. Although the results of TKA have been generally improving, there remain major clinical problems related to loosening and unexplainable residual pain [7, 25]. Loosening can occur due to polyethylene insert wear and knee instability caused by implant malrotation. Much of the residual pain after TKA is unexplainable, but iliotibial band traction or friction due to rotational disorder has been reported to cause lateral knee pain [17]. Therefore, it is very important to place femoral components in the correct rotation angle.

Y. Tashiro (✉) · S. Matsuda · K. Okazaki · S. Kawahara · Y. Iwamoto
Department of Orthopaedic Surgery, Kyushu University Hospital, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan
e-mail: 11yasu@med.kyushu-u.ac.jp

Y. Tashiro · M. Uemura · M. Hashizume
Department of Advanced Medicine and Innovative Technology, Kyushu University Hospital, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan

Anatomical and functional studies have proposed the transepicondylar axis or AP axis as a reliable rotational landmark to properly place the femoral component [4, 6, 8, 11, 19, 27, 28]. The surgical transepicondylar axis (SEA), a line between the medial sulcus and lateral epicondylar prominence, or the clinical transepicondylar axis (CEA), a line between the medial and lateral epicondylar prominences, is not always easily identifiable landmark during surgery because of their geometry and the presence of obscuring soft tissues [4, 18]. The AP axis is also not easy to find in cases with trochlear wear or intercondylar osteophytes. The trochlear line connecting the most anterior projections of the lateral and medial femoral condyles has been proposed as an additional reference axis for determining femoral rotation in a cadaveric study of 50 non-degenerative knees [30], but the anterior portion of distal femur has been observed to be negatively influenced by large osteophytes in degenerative knees.

Therefore, in TKA surgical procedures, surgeons often set the rotational cutting jig to the posterior condylar axis (PCA) as a visible landmark and estimate the transepicondylar axis based on the twist angel measured on preoperative CT or MRI images [3, 20]. By using CT or MRI images preoperatively, the incidence of patellofemoral subluxation has improved in recent years. While MRI images can clearly detect articular cartilage of posterior femoral condyles [24], surgical planning based on CT or X-ray does not include articular cartilage, and therefore differences in the cartilage thickness in each compartment could reduce the accuracy when determining the rotation of the femoral component, especially in osteoarthritis knee patients whose articular cartilage wear is localized only in a hemi-compartment (Fig. 1).

The purpose of this study was to clarify whether differences in the cartilage thickness on medial and lateral posterior condyles affect the rotational alignment of the femoral component in TKA. We therefore hypothesized that the cartilage thickness might cause some errors in the femoral rotation.

Materials and methods

Forty patients with varus knees waiting for TKA participated in the present study. Nine men and 31 women with a mean age of 76 years (range, 58–85) were included (Table 1). All cases were osteoarthritis (OA) and none of the subjects had rheumatoid arthritis (RA). The exclusion criteria included valgus knees and any history of osteotomy to the affected limb. The study protocol was reviewed and approved by the institutional review board, and all patients gave their informed consent before they were included.

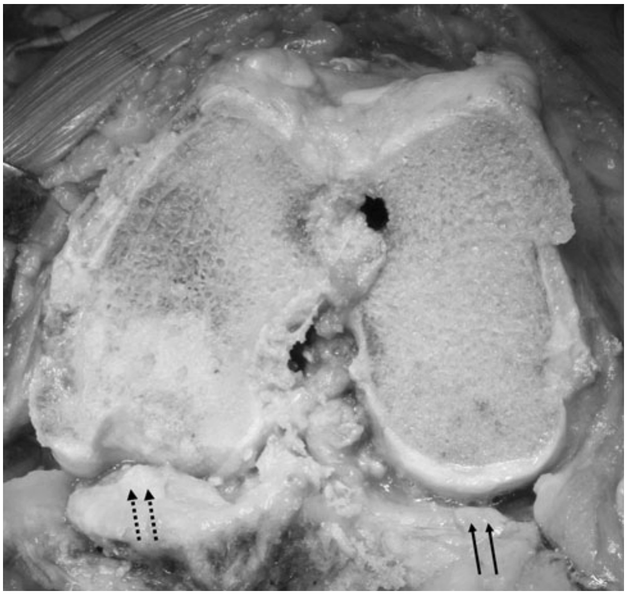

Fig. 1 The axial cross section of the *left* distal femur is shown. The articular cartilage on the posterolateral condyle is well preserved (*arrows* with *full line*), while that on the posteromedial condyle is worn off (*arrows* with *dotted line*)

Table 1 Patient demographics

Gender	*n*	Mean ± SD
Male	9	
Female	31	
Age		76 ± 6 (range, 58–85)
BMI		27.5 ± 3.9 (range, 18.7–35.8)
HKAA		
Affected knee		166.8 ± 6.2° (range, 150–176)
Opposite knee		170.1 ± 6.4° (range, 153–182)*

HKAA hip-knee-ankle angle

* 15 of the opposite knees also either previously had TKA or developed it later, so their HKAA values were recorded shortly before surgery. None of these opposite 15 TKAs were included in this study

Evaluation

Magnetic resonance imaging (MRI) scans of axial sections through the affected knees were made preoperatively. The scans were controlled to make the cross section perpendicular to the mechanical axis of the femur on the coronal plane and perpendicular to the tangent line of the distal femur on the sagittal plane, so that the surgical section of the actual femur could be simulated (Fig. 2a, b). The articular cartilage thickness on each of the medial and lateral posterior condyles was measured with MRI axial images. The angle between the CEA and the PCA was also measured as the condylar twist angle (CTA), with and without articular cartilage (Fig. 3a, b). The difference between the CTA measured with cartilage

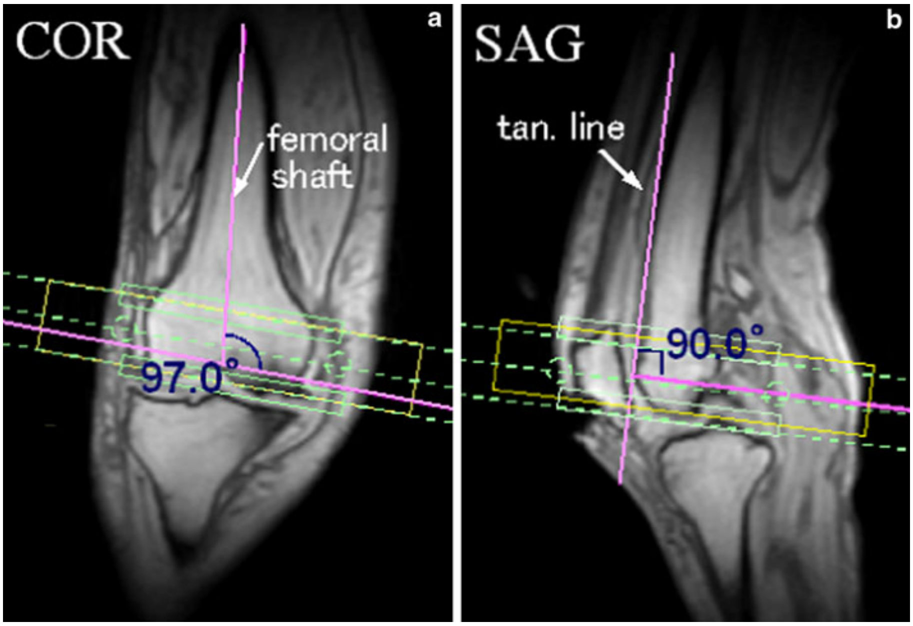

Fig. 2 **a** In order to simulate the actual surgical section, scans were controlled to make the cross section perpendicular to the mechanical axis of the femur on the *coronal plane*. In this case, 7° of valgus angle to the femoral *bone shaft* was established based on the preoperative surgical planning. **b** On the sagittal plane, scans were controlled to make the cross section perpendicular to the tangent line of the distal femur (*tan.-line*) to avoid notching

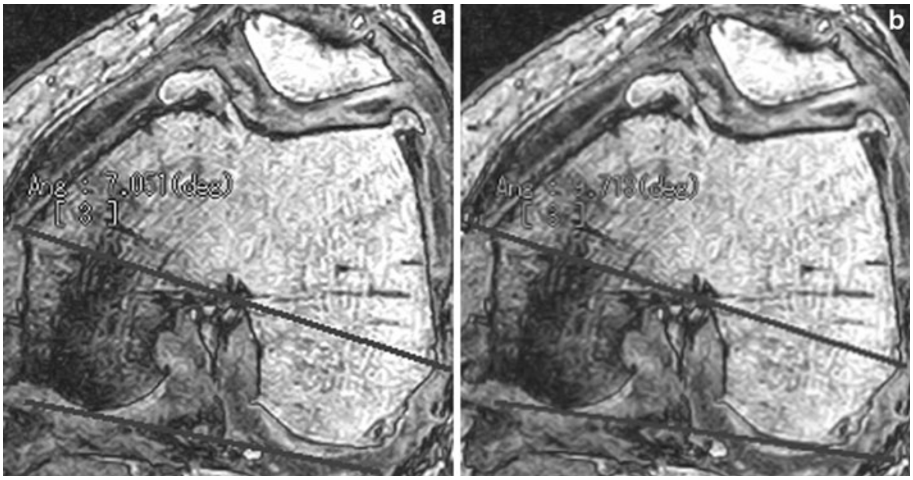

Fig. 3 Simulated cross sections of distal femur are shown. The angle between the posterior condylar axis and the transepicondylar axis (Condylar twist angle; CTA) was measured. **a** The CTA was measured with the articular cartilage included. **b** The CTA was enlarged when it was measured without the articular cartilage

(CTA-cartilage [+]) and the CTA measured without cartilage (CTA-cartilage [−]) was calculated, and a histogram was made. We used the 3D DICOM image processing software program (Real INTAGE, CYBERNET SYSTEMS Co, Tokyo, Japan) for the measurements. All measurements were repeated three times on three different days by two observers (YT and SK) who were blinded to the results recorded by the other observer. The MRI system used in this study was a horizontal open MRI at 0.4 T (APERTO, Hitachi Medical Co, Tokyo, Japan). The imaging pulse sequence was a balanced steady-state acquisition with rewinded gradient echo sequence (TR/TE = 40/10 ms, flip angle = 30°, field of volume = 140 mm, thickness = 1.0 mm).

During the TKA surgical procedure, the distal femur was cut perpendicular to the mechanical axis in coronal alignment. In the sagittal alignment, the cutting was intended to be perpendicular to the anatomical axis of the distal femur to avoid notching. Three to seven degrees of external rotation relative to the posterior condyles was established so that the rotational alignment could be adjusted to the surgical epicondylar axis (SEA).

The articular cartilage thickness of the actual posterior femoral condyle was measured to confirm the preoperative MRI measurement. Resected specimens of the femur were sliced at the lowest peak of the posterior femoral condyle, and the cartilage thickness was surveyed using a digital caliper with an accuracy of ± 0.01 mm. Two of the co-authors (SM and MU) independently surveyed three points around the lowest peak of the posterior femoral condyle and adopted the mean value.

The coronal alignment of the affected limb was evaluated as a hip-knee-ankle angle (HKAA) that was the medial angle between the mechanical axis of the femur and that of the tibia.

Statistical analysis

The paired *t* test was used to compare the cartilage thickness of the medial and lateral posterior condyles. The relationship between cartilage thickness measured by MRI and resected specimens was assessed using Pearson's correlation coefficient in order to validate the MRI measurement. CTA-cartilage [+] was compared with CTA-cartilage [−] using a paired *t* test. The relationships between the differences in the values of the CTA-cartilage [+] and CTA-cartilage [−], and the lateral minus medial values of the posterior condyle cartilage thickness, and HKAA, were also assessed using Pearson's correlation coefficient. A P value of 0.05 or less was considered to indicate a significant difference.

To examine the reproducibility of this method, all measurements were repeated three times each by two different observers who were blinded to the results reported by the other observed, and the intraclass/interclass correlation coefficients (ICC) were assessed. A repeated one-factor ANOVA was performed to calculate the intra-observer reliability, ICC (1.3), from the data recorded during the three measurements. The inter-observer reliability, ICC (2.3) of each angle or thickness was calculated using an unrepeated two-factor ANOVA from the averages of three measurements made by each of the two observers.

Results

The measurement reliabilities of the angles and thickness were good to excellent (ICC:0.81–0.99) except for the medial cartilage thickness in MRI by SK (ICC: 0.72) (Table 2). The mean articular cartilage thickness was significantly thicker on the lateral condyle than on the medial condyle according to the MRI measurements ($P < 0.01$). A survey of resected specimens showed the cartilage thickness to also be significantly thicker on the lateral condyle ($P < 0.01$). The thicknesses measured by MRI and in resected specimens revealed a very strong correlation ($r = 0.93$, $P < 0.01$).

The paired *t* test revealed a significant difference between the CTA-cartilage [+] (mean, 5.1 ± 2.1°) and CTA-cartilage [−] (mean, 6.8 ± 2.0°) ($P < 0.01$), and the distribution of the difference was represented in the histogram (Fig. 4). A total of 12 out of 40 knees (30%) showed more than 2 degrees of difference. A strong correlation was demonstrated between the CTA-cartilage [−] minus CTA-cartilage [+] values (Y) and the lateral minus medial values (X) of cartilage thickness on the posterior condyle ($r = 0.65$, $P < 0.01$) (Fig. 5), and the correlation was represented by the linear regression line of $Y(^\circ) = 1.1X–0.2\ (^\circ)$, with a 99% prediction band. On the other hand, HKAA had almost no correlation with the CTA-cartilage [−] minus CTA-cartilage [+] values ($r = 0.20$, $P = 0.22$). The mean HKAA was 166.8 ± 6.2°.

Discussion

The most important finding of the present study was that the CTA could be overestimated by as much as 2° in about 30% of TKA cases if the cartilage thickness on the

Table 2 The measured angles/thicknesses and reliabilities

MRI	Mean ± SD	Examiner	Intra-observer reliability ICC (1.3)	Inter-observer reliability ICC (2.3)
Cartilage thickness				
Medial	0.3 ± 0.2 mm	YT × 3	0.81	0.87
	0.4 ± 0.2 mm	SK × 3	0.72	(YT × 3 & SK × 3)
Lateral	1.7 ± 0.6 mm*	YT × 3	0.94	0.94
	1.8 ± 0.5 mm*	SK × 3	0.86	(YT × 3 & SK × 3)
CTA-cartilage [+]	5.1 ± 2.1°	YT × 3	0.97	0.85
	5.2 ± 2.0°	SK × 3	0.99	(YT × 3 & SK × 3)
CTA-cartilage [−]	6.8 ± 2.0° **	YT × 3	0.97	0.87
	6.7 ± 1.9° **	SK × 3	0.98	(YT × 3 & SK × 3)
CTA-cartilage [−]	1.7 ± 0.7°	YT × 3	0.94	0.83
Minus CTA-cartilage [+]	1.5 ± 0.7°	SK × 3	0.92	(YT × 3 & SK × 3)
Specimen				
Cartilage thickness				
Medial	0.3 ± 0.3 mm	SM × 3	0.93	0.86
	0.4 ± 0.3 mm	MU × 3	0.89	(SM × 3 & MU × 3)
Lateral	2.0 ± 0.5 mm*	SM × 3	0.92	0.87
	1.8 ± 0.6 mm*	MU × 3	0.96	(SM × 3 & MU × 3)

* $P < 0.01$ compared with the medial cartilage thickness

** $P < 0.01$ compared with the CTA-cartilage [+]

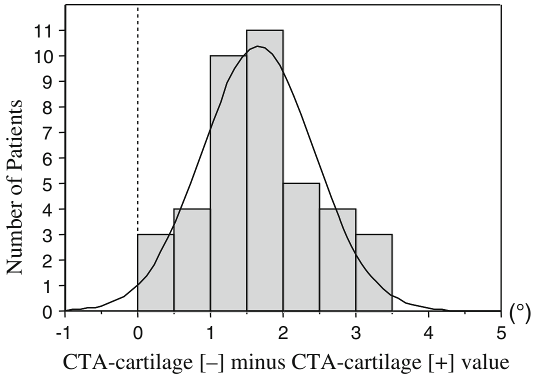

Fig. 4 The histogram represents the distribution of CTA-cartilage [−] minus CTA-cartilage [+] values. A total of 12 out of 40 knees (30%) showed more than 2 degrees of difference

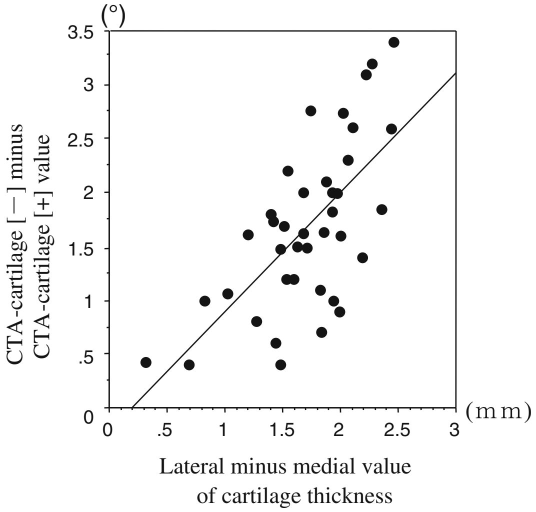

Fig. 5 A strong correlation was demonstrated between the CTA-cartilage [−] minus CTA-cartilage [+] values and the lateral minus medial values of the cartilage thickness on posterior condyles

posterior condyles is neglected. It is important to set the rotational alignment correctly for TKA techniques, because it affects patellar tracking, ligament balance during knee flexion and tibiofemoral congruity. Many surgeons set cutting guide systems to both posterior condyles as an easily identifiable landmark, and align the femoral component to within some degree of external rotation from the PCA in order to make it parallel to the SEA or CEA [3, 6]. However, the presence of articular cartilage wear localized only in the hemi-compartment might make the femoral rotation inaccurate one. Femoral implant malrotation causes instability in knee flexion, polyethylene insert wear due to tibiofemoral incongruity and iliotibial band traction, and thus can lead to the occurrence of early loosening or residual pain [17, 25]. The externally malrotated femoral component theoretically causes increased polyethylene wear, particularly in early flexion, but the limits of the rotation angles that a TKA can tolerate have not yet been defined. A recent editorial indicated that a change of 2–3 degrees in alignment during knee flexion or a change of 2–3 mm in bone cut on the posterior femoral condyle can make a difference in the ligament balance and clinical functional outcome [14]. In varus knees, medial ligament releases are often performed to achieve a correct ligament balance in extension, but a clinical study of 54 cruciate-retaining TKA cases reported the posteromedial corner and the superficial medial collateral ligament release together result in a 2.4° external femoral rotation in knee flexion [13]. If the influence of such medial releases is combined with that of cartilage thickness neglection, then the femur can be nearly 4–5° externally rotated, thus leading to medial looseness in knee flexion. The purpose of this study was to clarify whether differences in the cartilage thickness on the posteromedial and posterolateral condyles influence the rotational alignment of the femoral component for TKA.

One of the limitations of this study was that the comparison of the CTA-cartilage [+] and CTA-cartilage [−] was based on the MRI measurement, but the articular cartilage thickness shown by MRI can vary depending on the imaging pulse sequence. We adopted a gradient echo sequence with a relatively low flip angle of 30° and a short repetition time (TR) of 40 ms so that we could clearly distinguish articular cartilage from subchondral bone and joint fluid. This imaging sequence makes it possible to highlight T2 weighted areas such as articular cartilage [12]. Another issue was whether the cross section we used for the measurement of CTA in MRI was parallel to the surgical section or not. In order to solve this problem, we simulated the surgical section of the femur and minimized the error. The similar cartilage thickness pattern and the very strong correlation between the MRI and surgical specimens confirmed the accuracy of the MRI measurement.

Evaluation of the articular cartilage thickness in posterior femoral condyles showed substantially more cartilage wear in the posteromedial condyle than in the posterolateral condyle. This localization of wear in the hemi-compartment would have led to a more enlarged CTA-cartilage [-] than CTA-cartilage [+]. The linear regression line of Y (°) = 1.1X–0.2 (°) (Y: CTA-cartilage [−] minus CTA-cartilage [+] value, X: the posterolateral minus posteromedial value of cartilage thickness) means that if there is a 2 mm (or 3 mm) difference in the cartilage thickness between both posterior condyles, an almost 2° (or 3.1°) increase in the externally rotated implantation of the femoral component is predicted compared with the cases without any differences in cartilage thickness. This also means that a more externally rotated femoral implantation is likely to occur when surgical planning using X-ray or CT, which does not consider articular cartilage, is used.

In addition, this linear regression line suggests that a <1 mm difference in the cartilage thickness between both sides predicts only a 0.9° external rotation at most, which could be negligible.

An analysis of the histogram of the CTA-cartilage [−] minus CTA-cartilage [+] value suggests that as many as 30% of medial osteoarthritic knees could be implanted with more than 2 degrees of external rotation. Previous studies have reported that rotational mismatch of femoral and tibial articulation can lead to patellofemoral dysfunction, knee instability, and tibial polyethylene wear [15], although most of patellofemoral complications were due to internal malrotation of the femoral implant [1, 2, 5, 21]. Internal rotation of the femoral component moves the groove portion of the femoral component relatively medially, and increases the lateral force vector on the patella [26]. A cadaveric study of implanted femoral components with from 5° internal rotation to 5° external rotation indicated that the femoral component rotation parallel to the epicondylar axis thus minimized the patellofemoral shear forces [23].

An excessive external rotation of the femoral components theoretically could worsen the tibiofemoral congruity and increase the risk of polyethylene wear over the long term. An in vitro study using a knee testing device reported that a 3° external rotation of the femoral component caused rotational incongruity in knee extension between the femoral and tibial components [22]. The loss of rotational congruity would decrease tibiofemoral contact areas, moving the contact point on the tibial surface posteriorly, and thus could potentially lead to polyethylene wear of the tibial surface. A previous study with a finite element model revealed that malalignment in axial rotation detrimentally increased contact stresses at the tibiofemoral articulation [10]. Moreover, external malrotation of the femoral components can cause residual pain after TKA. Recently, a systemic in vivo study using a guided motion TKA documented that posterior translation of the lateral condyle and relative internal tibial rotation during flexion forced stretching or friction of the iliotibial band and caused lateral knee pain in 77 cases (7.2%) in a series of 1,070 TKAs [17]. A computer simulation study suggested that the use of rotating platforms might reduce the unfavorable influence arising from femoral component malrotation [9], but long-term follow-up of these kinds of implants is still needed, and we believe the basic principle in TKA is still to place implants in the accurate rotation angle.

Conclusion

The cross section of the distal femur was stimulated with high accuracy, and the CTA was evaluated both with and without articular cartilage. In conclusion, the cartilage thickness of the posterior condyles may be a possible reason for errors in the rotation of the femoral component, and the CTA can be estimated to be significantly larger when the cartilage is neglected. In about 30% of cases of TKA which are planned without considering the cartilage thickness, the femoral component may be implanted with more than 2° of external rotation compared to the planned location. When surgeons choose the technique to set the rotational cutting jig to the PCA and estimate the transepicondylar axis, they would need to adjust for this by surgical planning based on MRI, or by aligning the femoral component directly to the transepicondylar axis in order to improve femoral rotation.

Acknowledgments We thank Ms. Sumako Nishimura (Department of Advanced Medical Initiatives, Faculty of Medical Sciences, Kyushu University) for her assistance in operating the MRI system.

References

1. Abadie P, Galaud B, Michaut M, Fallet L, Boisrenoult P, Beaufils P (2009) Distal femur rotational alignment and patellar subluxation: a CT scan in vivo assessment. Orthop Traumatol Surg Res 95:267–271
2. Akagi M, Matsusue Y, Mata T, Asada Y, Horiguchi M, Iida H, Nakamura T (1999) Effect of rotational alignment on patellar tracking in total knee arthroplasty. Clin Orthop Relat Res 366:155–163
3. Akagi M, Yamashita E, Nakagawa T, Asano T, Nakamura T (2001) Relationship between frontal knee alignment and reference axes in the distal femur. Clin Orthop Relat Res 388:147–156
4. Arima J, Whiteside LA, McCarthy DS, White SE (1995) Femoral rotational alignment, based on the anteroposterior axis, in total knee arthroplasty in a valgus knee. J Bone Jt Surg Am 77:1331–1334
5. Berger RA, Crossett LS, Jacobs JJ, Rubash HE (1998) Malrotation causing patellofemoral complications after total knee arthroplasty. Clin Orthop Relat Res 356:144–153
6. Berger RA, Rubash HE, Seel MJ, Thompson WH, Crossett LS (1993) Determining the rotational alignment of the femoral component in total knee arthroplasty using the epicondylar axis. Clin Orthop Relat Res 286:40–47
7. Bonnin MP, Basiglini L, Archbold HA (2011) What are the factors of residual pain after uncomplicated TKA? Knee Surg Sports Traumatol Arthrosc 19:1411–1417
8. Churchill DL, Incavo SJ, Johnson CC, Beynnon BD (1998) The transepicondylar axis approximates the optimal flexion axis of the knee. Clin Orthop Relat Res 356:111–118
9. Colwell CW Jr, Chen PC, D'Lima D (2011) Extensor malalignment arising from femoral component malrotation in knee arthroplasty: effect of rotating-bearing. Clin Biomech 26:52–57
10. D'Lima DD, Chen PC, Colwell CW Jr (2001) Polyethylene contact stresses, articular congruity, and knee alignment. Clin Orthop Relat Res 392:232–238
11. Griffin FM, Insall JN, Scuderi GR (1998) The posterior condylar angle in osteoarthritic knees. J Arthroplasty 13:812–815
12. Hashemi RH, Bradley WG Jr, Lisanti CJ (2004) MRI: the basics, 2nd edn. Williams & Wilkins, Philadelphia
13. Heesterbeek PJ, Wymenga AB (2010) Correction of axial and rotational alignment after medial and lateral releases during

balanced gap TKA. A clinical study of 54 patients. Acta Orthop 81:347–353

14. Heesterbeek PJ, Wymenga AB (2010) PCL balancing, an example of the need to couple detailed biomechanical parameters with clinical functional outcome. Knee Surg Sports Traumatol Arthrosc 18:1301–1303
15. Lee DH, Seo JG, Moon YW (2008) Synchronisation of tibial rotational alignment with femoral component in total knee arthroplasty. Int Orthop 322:223–227
16. Lee SY, Matsui N, Kurosaka M, Komistek RD, Mahfouz M, Dennis DA, Yoshiya S (2005) A posterior-stabilized total knee arthroplasty shows condylar lift-off during deep knee bends. Clin Orthop Relat Res 435:181–184
17. Luyckx L, Luyckx T, Bellemans J, Victor J (2010) Iliotibial band traction syndrome in guided motion TKA. A new clinical entity after TKA. Acta Orthop Belg 76:507–512
18. Mantas JP, Bloebaum RD, Skedros JG, Hofmann AA (1992) Implications of reference axes used for rotational alignment of the femoral component in primary and revision knee arthroplasty. J Arthroplasty 7:531–535
19. Matsuda S, Matsuda H, Miyagi T, Sasaki K, Iwamoto Y, Miura H (1998) Femoral condyle geometry in the normal and varus knee. Clin Orthop Relat Res 349:183–188
20. Matsuda S, Miura H, Nagamine R, Mawatari T, Tokunaga M, Nabeyama R, Iwamoto Y (2004) Anatomical analysis of the femoral condyle in normal and osteoarthritic knees. J Orthop Res 22:104–109
21. Matsuda S, Miura H, Nagamine R, Urabe K, Hirata G, Iwamoto Y (2001) Effect of femoral and tibial component position on patellar tracking following total knee arthroplasty: 10-year follow-up of Miller-Galante I knees. Am J Knee Surg 14:152–156
22. Ries MD, Salehi A, Laskin RS, Bourne RB, Rand JA, Gustilo RB (1998) Can rotational congruity be achieved in both flexion and extension when the femoral component is externally rotated in total knee arthroplasty? Knee 5:37–41
23. Miller MC, Berger RA, Petrella AJ, Karmas A, Rubash HE (2001) Optimizing femoral component rotation in total knee arthroplasty. Clin Orthop Relat Res 392:38–45
24. Ogino S, Huang T, Watanabe A, Iranpour-Boroujeni T, Yoshioka H (2010) Magnetic resonance imaging of articular cartilage abnormalities of the far posterior femoral condyle of the knee. Acta Radiol 51:52–57
25. Piedade SR, Pinaroli A, Servien E, Neyret P (2009) Revision after early aseptic failures in primary total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 17:248–253
26. Poilvache PL (2001) The patella in total knee replacement: technical aspects on the femoral side. Knee Surg Sports Traumatol Arthrosc 9(Suppl 1):S13–S18
27. Poilvache PL, Insall JN, Scuderi GR, Font-Rodriguez DE (1996) Rotational landmarks and sizing of the distal femur in total knee arthroplasty. Clin Orthop Relat Res 331:35–46
28. Rossi R, Bruzzone M, Bonasia DE, Marmotti A, Castoldi F (2010) Evaluation of tibial rotational alignment in total knee arthroplasty: a cadaver study. Knee Surg Sports Traumatol Arthrosc 18:889–893
29. Scuderi GR, Komistek RD, Dennis DA, Insall JN (2003) The impact of femoral component rotational alignment on condylar lift-off. Clin Orthop Relat Res 410:148–154
30. Won YY, Cui WQ, Baek MH, Yun TB, Han SH (2007) An additional reference axis for determining rotational alignment of the femoral component in total knee arthroplasty. J Arthroplasty 22:1049–1053